AMERICAN MUSEUM NOVITATES

Number 775 — Published by THE AMERICAN MUSEUM OF NATURAL HISTORY New York City — Jan. 29, 1935

55.1, 78 (82.9)

EARLY AND MIDDLE TERTIARY GEOLOGY OF THE GAIMAN REGION, CHUBUT, ARGENTINA[1]

BY GEORGE GAYLORD SIMPSON

INTRODUCTION

The originally Welsh settlement of Gaiman is situated approximately in latitude 43° 16′ South, longitude 65° 28′ West, on the north (left) bank of the Río Chubut in Chubut Territory (central Patagonia), Argentina. The valley bottom is here alluvial, but directly north of Gaiman and its westward extension Gaiman Nuevo, an abrupt slope, in places almost a vertical cliff, rises to the high pampa level, and a similar slope faces this and bounds the valley on the south side. In these scarps is exposed a thick series of Tertiary and, according to some authorities, older strata.

These exposures are of exceptional geological interest. Among the many problems on which they do or are supposed to cast light are the relationships of the marine Salamanca to the terrestrial Casamayor Formation, the position and nature of the Cretaceous-Tertiary contact, the beginnings of Andine orogeny, the relation of the terrestrial Colhué-Huapí to the marine Patagonian Formation, the time of extinction of South American dinosaurs, and the ages of these various formations and also of the Santa Cruz Formation (not present here as such). From near here came most of the fossil Cetacea known from South America, a large percentage of the fossil penguins known from anywhere in the world, the type specimen of *Colpodon*, which has given its name to the so-called *Colpodon* Beds = Colhué-Huapí Formation, and many other very important fossils, terrestrial and marine, vertebrate and invertebrate. It is also a possible field for exploration for petroleum, which cannot be intelligently directed or its profitability reasonably forecast until the surface formations are understood.

This importance has long been recognized and the region has been studied by a number of geologists, including Roth (1908), Ameghino (1906, based on collections and data communicated to him by Roth), Windhausen (1921), and Frenguelli (1927). The Scarritt Expeditions, 1930–'31 and 1933–'34, have several times passed through or near

[1] Publications of the Scarritt Expeditions, No. 23.

Gaiman, and in 1933 we spent some time there, collecting fossils at different levels and measuring several detailed geological sections. Our results are so different from what was anticipated and cast so much new light on all the problems mentioned above that it seems necessary to publish them as promptly as possible.

It should be mentioned that in 1933 we coöperated in this region with Sr. Alejandro F. Bordas, representing the Museo Argentino de Ciencias Naturales, Buenos Aires. He accompanied us while we were working there and he continued his work after we left, effecting junction with us again in a different region. His collections and data corroborate ours, although they were not directly employed in the preparation of this paper.

The late Mr. T. N. Tappen of "La Araucana," Gaiman, placed us deeply in his debt by his hospitality and assistance, and various friends in Trelew also aided us in ways less directly bearing on the present subject.

RÉSUMÉ OF PREVIOUS OPINIONS

The general nature of the problem can best be sketched by brief mention of previous views, some details of which will be more adequately discussed in dealing with our own results. Roth (1899, p. 382) was speaking of Gaiman Nuevo exposures when he wrote "el tercer yacimiento, que se halla en la costa misma del Río Chubut, se compone de una cuárzita que se encuentra debajo la formación de toba cretácea de Dinosaurios. En este sitio he encontrado restos de Mamíferos mezclados con los de Reptiles, entre los cuales abundan principalmente los de Tortugas." In view of later statements, note that the phrase applied to the tuff means "Dinosaur tuff" not "tuff with Dinosaurs" (an important distinction), that the only reptiles specified are tortoises and that nothing is said of marine shells. In 1901 (page 255) Roth named *Lelfunia haugi*, which came from this horizon and locality although he wrote only that it was from a "Formación cretácea superior," and in 1903 (p. 143) he described *Monolophodon minutus* with only the slight further data that it was from a quartzite on the Río Chubut near the [Welsh] Colony.

Ameghino at first (1901–1902, p. 41 of the separate edition of 1903) reproached Roth with the inexactness of his data and hazarded the mistaken guess that Roth's third locality, actually that near Gaiman Nuevo, was in the Valle de los Mártires.[1] Later (1906, pp. 94–95) Ameghino

[1]Also on the Chubut River, but many leagues farther west. Ameghino said he had some mammal and tortoise remains from there, and Roth also later indicated mammal beds in the valley. We traveled up this valley and found no mammal-bearing formation. Roth's indication is probably an erroneous correlation, and I suspect that Ameghion's mammal teeth (never described as far as I know) came either from nearer Gaiman or from some locality well outside the valley. In any case the locality here in question was not in the Valle de los Mártires.

wrote, ". . . Les couches marines du salamanquéen sont limitées par un ruban de grès à gros grains mélangés avec des débris de coquilles triturées et avec des os plus ou moins roulés (parfois aussi intacts) de Poissons, de Tortues et de Mammifères de la faune du Notostylops. . . . Une des plus intéressantes localités de ce ruban, est celle découverte par M. Roth en face de Gaiman.[1] Ici, enchâssé dans la même quartzite, mélés au coquilles triturées de la mer salamanquéenne on y trouve une quantité considérable d'ossements de Poissons, de Crocodiles et de Tortues fluviatiles, avex des dents et des ossements de Mammifères de la faune notostylopéenne, tels que *Notostylops, Polydolops, Didolodus, Adpithecus, Trigonostylops*, etc." The locality is correctly shown by Ameghino on the accompanying sketch map. These new data were doubtless due to personal communication from Roth, as he apparently had not then published even the exact locality and as this work of Ameghino contains reference to conversations with Roth and also other data clearly derived from personal communication.

Carlos Ameghino has informed me that he never examined this region, and it may be inferred that unpublished data from Roth were Ameghino's chief or whole authority. It is therefore surprising to find that when Roth himself published on this occurrence (1908), his statements were widely at variance with Ameghino's. He said (p. 112) "Das liegende wird von einem grobkörnigen Sandstein gebildet. In diesem habe ich die bereits erwähnten Reste der *Notostylops* Fauna gefunden. Darüber folgt hellgrauer Tuff der Übergangsformation, der hier keine Fossilien enthält. Auf diesem liegt konkordant ein etwas härtere, dunkelgraue Tuffbank, in der die eben erwähnten Säugetierreste nebst vereinzelten Meeresmuscheln vorkommen." This description we found to be essentially correct, although the correlations are not. Roth says nothing of Salamanca shells mingled with Casamayor (*Notostylops* Beds) mammals, and we found none. I am convinced that they do not exist, because this bed is much later than the Salamanca. Ameghino's statement can only be a misunderstanding of some statement by Roth.[2] The same was probably true of the list of genera given by Ameghino. Any of these genera could perhaps occur here, but in fact, as far as I know, the only forms actually known then were the two named by Roth, which are generically related to or identical with Ameghino's

[1]The phrase suggests that the locality is across the river from Gaiman, but it is on the same side, as correctly shown in Ameghino's map.

[2]The quotation from Roth shows how the misunderstanding could arise. He does speak of mingled shells and mammals, but these were supposed to be in the base of the Patagonian Formation. Ameghino may easily have understood him to mean the older mammals, in which case, according to the view they shared, the marine shells could only have been from the Salamanca.

Isotemnus and *Polystylops* and a *Polydolops* then in Roth's Collection but not described. I have studied Roth's Collection (in the Museo de La Plata) and it contains only these three genera and some fragmentary bones. There are no dinosaurs, and when Roth called this the "Dinosauriersandstein" he was expressing an opinion and not announcing a discovery. He meant merely that he thought the beds to be Cretaceous and that he correlated them with strata which do contain dinosaurs elsewhere.

It had long been known that at least part of the upper portions of the cliffs in this part of the valley is formed by the marine Patagonian Formation, and also that terrestrial mammals occur, since *Colpodon* had been found. Ameghino (1906, pp. 222–226) pointed out that these younger mammals are apparently in the base of the Patagonian Formation, and that there are terrestrial beds interstratified with the lower marine beds. He also said that at the Castillo (south of Trelew, and an outlier of the eastern extension of the cliffs opposite Gaiman) there are *Notostylops* Beds (i.e., Casamayor) below these, and he correlated them with the lithologically different sandstones near Gaiman Nuevo, across the river. In the study already quoted, Roth (1908) gave the Gaiman [Nuevo] succession as Cretaceous sandstones with *Notostylops* fauna at the base, followed by the "Transition Formation" (by which he implied correlation with the Deseado or *Pyrotherium* Beds), without fossils, and capped by the Tertiary marine Patagonian Formation with the terrestrial *Colpodon* fauna at its base.

Thirteen years after Roth's publication, Windhausen (1921) discussed the geology of this area in some detail. He stressed the fact that the lower beds, the sandstones and quartzites of Roth and Ameghino, around Gaiman on the north side of the river, consist of interdigitating sands and clays[1] and he referred them to the Salamanca Formation. He stated that the upper sandstones [and clays] of Gaiman contain no fossils. The correlation is thus based on a belief in continuity with beds, such as those farther up the valley, which do contain fossils, and (unintentionally, of course) he gives the impression that the continuity is established. In fact this is not true. The exposures are not continuous and there is no warrant for assuming that the beds at Gaiman have anything to do with the fossiliferous Salamanca elsewhere. He said (p. 23) that the clays are those considered by Ameghino as "Notostylopeano," Casamayor, and that if they do indeed contain the *Notostylops*

[1]There is no evidence that interdigitation in the sense of Windhausen's "engranaje" really exists. The beds are lenticular.

fauna, then the Casamayor[1] clays and Salamanca sands interdigitate, and he so showed them in a diagram. This seemingly overlooks the fact that it was the sands from which the mammals came and which Ameghino considered as containing the *Notostylops* fauna, that it is not clear that the sands and clays really interdigitate (instead of simply being lenses of a unified but heterogeneous formation), and that the Salamanca age of any part of this series was an assumption based on no evidence, palaeontological or stratigraphic. In a note added later (p. 25) he announced that the clays are really part of the "Estratos con Dinosaurios," and, by implication at least, that they are not Casamayor. This also, was unsupported by any evidence. He at first agreed with Roth in considering the intermediate tuffs as of Deseado age, but in a note in the same work (p. 25) added later that they were older than the Deseado, but did not specifically state that they were Casamayor, although this seems to be implied. He also said (p. 26) that the *Colpodon* fauna occurs in the upper part of these tuffs and before the Patagonian marine transgression. In 1924 (opposite p. 194) he correlates the clays and sands, at the base of the Gaiman section, with the upper part of the "Estratos con Dinosaurios," shows a tectonic unconformity above them, then the Casamayor, an erosional unconformity, the Deseado and Colhué Huapí (conformable) and an upper erosional unconformity followed by the Patagonian marine.

Frenguelli (1927) gave many more details of these exposures, including measured sections.[2] Some of his correlations are discussed below in comparison with my own views. As regards the Gaiman exposures, on which attention had hitherto been largely concentrated, he believed (section p. 237 and accompanying description) that the basal sands and clays are of the "Estratos con Dinosaurios" and are tilted and followed by an angular unconformity above which begins immediately the Patagonian with the mammals in its upper part and not in (Roth, Ameghino) or below (Windhausen) its base. He stated that no fossils occur in the sands, overlooking Roth's correct record of mammals and reptiles there. On the other (south) side of the valley, opposite Gaiman, he shows the same situation (p. 227 and descriptive text), except that here the mammals found by him were from a thick (30 meters) unsubdivided member forming the lower third of the Patagonian marine. He believed these

[1]Here and elsewhere it seems less confusing in indirect quotation to employ consistent geographic terms as much as possible even when the original author used some different equivalent.

[2]In discussing Frenguelli's interpretations of this part of the section, with most of which I cannot agree despite the accuracy of his field observations, it should be emphasized that he was primarily concerned with the uppermost marine beds of the south side of the valley and that his discussion of the older strata is incidental. These upper beds are not considered in the present paper, and consequently Frenguelli and I have concentrated on different parts of the section and discrepancies are not surprising.

mammals to be of Santa Cruz age. He drew the conclusion, inescapable on these premises, that the Casamayor, [Musters], Deseado, and Colhué-Huapí are here lacking and that the marine Patagonian Formation is represented only by its upper part, synchronous with the Santa Cruz.

To these various conflicting opinions, I now find it necessary to add another, radically different from any of them.

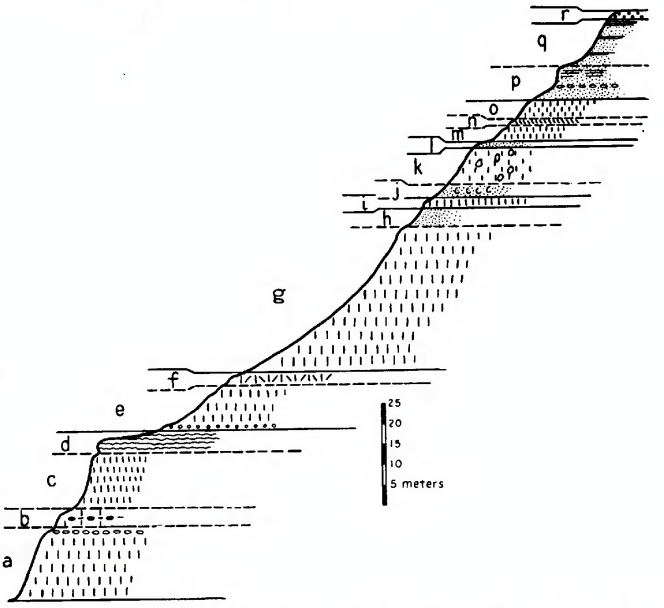

Fig. 1. Section of the south wall of the Chubut Valley, opposite Gaiman.
For description and explanation of reference letters, see Section 1, in the text.

SECTIONS

From five measured sections made by the Scarritt Expedition, I select two to illustrate the conditions on the south and north sides of the valley. Each section is given in temporal order, the oldest strata first.

1. South side of the Chubut Valley, opposite Gaiman (Fig. 1).
   - a. Very massive yellowish tuff, upper meter, more or less, with platy and honeycomb concretions. Base not exposed..... 18. meters.
   - b. Somewhat platy yellowish tuff, with various local concretionary zones..... 4.5 m.
   - c. Pale massive tuff, few concretions..... 13.5 m.
   - d. Very irregular, hard, rusty to yellow tuff with opaline concretions..... 5.5 m.

   41.5 m. 41.5 m.

	Plane of Erosion		
e.	Massive gray tuff with basal conglomerate. Land mammals. No marine fossils	11. m.	
f.	Soft, yellowish tuff with gypsum seams. No fossils	3. m.	
		14. m.	14. m.
	Sharp Division Probably an Erosion Plane		
g.	Thick-bedded, pale, yellowish tuff. Sparse *Ostrea hatcheri*, numerous sharks, rays, cetaceans, penguins	35. m.	
h.	Tuff and fine cross-bedded sandstone	4.5 m.	
i.	Hard, pale tuff	2.5 m.	
j.	Fine, soft, cross-bedded sand. Crabs and sand-filled burrows with molluscs	3. m.	
k.	Gray tuff, some *Ostrea hatcheri*. Sandy burrow fillings	9. m.	
l.	Sandy tuff and sand with many shells	1.5 m.	
m.	Massive yellowish tuff	4. m.	
n.	Sand and tuff	1.5 m.	
o.	Pale yellow tuff	4.5 m.	
		65.5 m.	65.5 m.
	Possible Plane of Erosion		
p.	Sandstone, yellow in lower and greenish-gray in upper part. Upper meter, more or less irregularly cemented. Local oyster banks	8.5 m.	8.5 m.
	Apparent Conformity		
q.	Pale yellow to pink, finely laminated sandstone, partly cross-bedded, some loess-like clay. No fossils seen	11.5 m.	11.5 m.
	Plane of Erosion		
r.	Heavy gravel	2. m.	2. m.
			143.0 m.

This corresponds approximately to Frenguelli's "Bryn Gwyn" section (1927, fig. 27), although apparently not taken at exactly the same part of the long cliff. My a–d is his Y and my e–o his X. The correspondence of the upper beds, which I did not study except to continue the line of measurements through them and which are not as thick

here as where Frenguelli took his section, is not so clear but probably my p is his A and my q his B.

2. "Pan de Azúcar" at Gaiman Nuevo (Fig. 3).

a.	Soft, fine, argillaceous sandstone. Base not exposed	8.5 meters.	
b.	White to pink arkosic sandstone. Turtle, crocodile, and mammal remains	1. m.	
c.	Soft, white argillaceous sandstone and greenish gray clay or bentonite	9. m.	
d.	Hard, lenticular sandstone, often weathering orange	6. m.	
		24.5 m.	24.5 m.
	Possible Erosion Plane		
e.	Yellowish and greenish clay or bentonite	4. m.	4. m.
	Possible Erosion Plane		
f.[1]	Tuff and bentonitic tuff. The lower part pale greenish-gray and more bentonitic, the upper part purer ash, hard and massive. Many concretions, especially in lower part	41.5 m.	
g.[1]	Hard gray tuff	2. m.	
h.[1]	Yellowish tuff, the lower four or five meters harder and with *Chubutolithes*	11.5 m.	
i.[1]	Very irregular concretionary tuff, showing ancient weathering	4.5 m.	
		59.5 m.	59.5 m.
	Marked Erosion Plane		
j.	Massive tuff with thin basal conglomerate. Land mammals	5.5 m.	5.5 m.
k.	Somewhat more yellowish tuff with *Ostrea hatcheri* and other marine molluscs	Top eroded and thickness of whole bed not determinable.	
			93.5 m.

This corresponds with Frenguelli's "Pan de Azúcar" section (1927, Fig. 37). My a–e is his Y, my f–i his Xa-Xf, and my j–k his Xg–Xi.

[1]Beds f–i were actually measured about one kilometer from the Pan de Azúcar, but there they have almost exactly the same thickness and character.

My h is his Xc–e. I found the thickness of the tuffs below that (my f–g, his Xa–Xb) to be 13.5 meters greater than he gives it, a marked discrepancy doubtless due to different methods of measuring,[1] to the fact that I measured them not on the Pan de Azúcar itself but on an adjacent cliff, and to the fact that he gives the thickness of his Xa as only approximate.

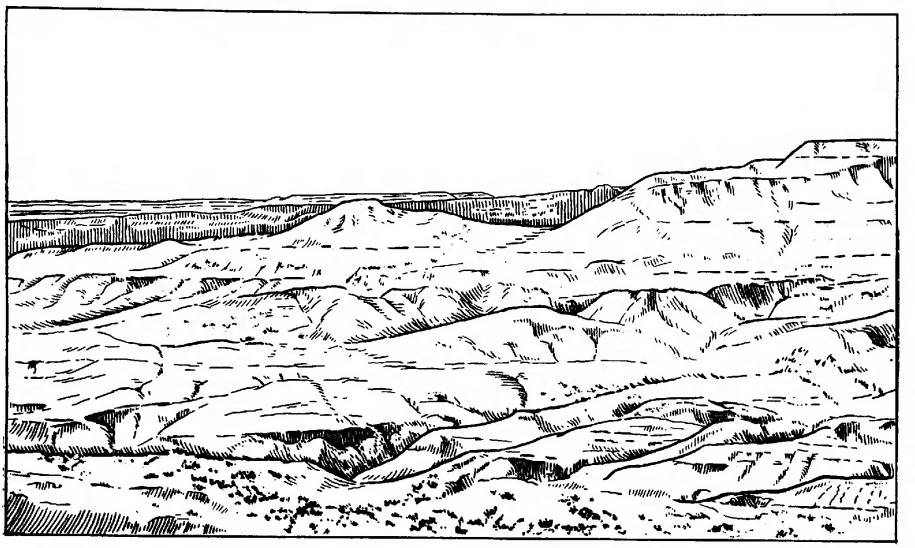

Fig. 2. Sketch of part of the south wall of the Chubut Valley, near Section 1 (Fig. 1).

The extreme upper part of the slope to the right is formed by post-Patagonian sandstones (*p–r* of section) and the main part of the slope, upper right, and the top of the small outlier, near the middle, by the Patagonian (*g–o* of section). The Trelew (*e, f* of section) forms a thinner horizontal band across the midline of the sketch, and the broken area below this is developed in the barren ?Casamayor (*a–d* of section).

FOSSILS

Section 1, stratum *e*. Although the fossils of this horizon are generally poorly preserved, they are fairly common and varied. Preparation is difficult and has not yet been done. The following identifications are believed to be exact, as given, but lack detail. In no case has a specific determination been possible. If conditions permit, a description of the fauna as such will appear later. At present, enough is known to make the stratigraphic relations fairly clear.

[1]My measurements were made by working up the section with a hand level, correcting for dip where necessary.

XENARTHRA

Megalonychidae

Gen. et sp. indet. Gravigrade, and apparently megalonychid, remains occur but no more exactly identifiable specimen is available to me.

Dasypodidae

?Stegotherium cf. *variegatum*. Isolated scutes agree almost exactly with Ameghino's description of this Colhué-Huapí species, but such scutes are inadequate for certain identification.

Gen. et sp. indet. A badly preserved skull does not appear to belong to any Santa Cruz genus in which this part is known, and comparable remains are not yet known from earlier formations. There are also some scutes which do not agree exactly with any yet described.

Glyptodontidae

?Propalaeohoplophorus sp. A number of scutes and a toothless jaw fragment seem to be of this genus, which ranges from the Colhué-Huapí into the Frías (post-Santa Cruz) Formation.

RODENTIA

Erethizontidae

Aff. *Sciamys* sp. A lower jaw represents a small rodent manifestly allied to the Santa Cruz *Sciamys* but generically distinct and apparently more primitive. It does not belong to *Protacaremys*.

LITOPTERNA

Proterotheriidae

Aff. *Thoatherium* sp. A partial lower jaw has characters both of *Licaphrium* and of *Thoatherium* of the Santa Cruz fauna. It may possibly be *Prothoatherium*, of Colhué-Huapí age, but Ameghino's description of the talonid of M_3 in that genus is not exactly applicable to this specimen.

Macraucheniidae

Theosodon sp. Poor material represents a form almost certainly of this genus, although apparently not of any known Santa Cruz species. It is very distinct from the Colhué-Huapí *Cramauchenia*.

NOTOUNGULATA

Leontiniidae

Colpodon sp. Several imperfect specimens are clearly of this genus. They do not agree exactly with Burmeister's specimens of *C. propinquus*, but the differences may not be specific. The type locality of the latter species is in this region, "near the mouth of the Río Chubut," and it is also recorded by Ameghino from the Colhué-Huapí Formation.

Interatheriidae

Cochilius sp. This Colhué-Huapí genus is common, and as far as I can observe its near allies *Interatherium* and *Protypotherium* of the Santa Cruz do not occur. Some specimens are very near *C. volvens*, but might prove to be specifically distinct, and there is a possibility that two species are present.

Hegetotheriidae

Hegetotherium sp. A common hegetothere is unlike any described Santa Cruz species, and might even be generically distinct although certainly

very close to *Hegetotherium*, which is common in the Santa Cruz and reported in the Colhué-Huapí. It may belong to *Tegheotherium*, which is from somewhere along the Río Chubut, but the agreement with Ameghino's description is not exact.

Gen. et sp. indet. Another hegetothere, intermediate in size between that just mentioned and the next, does not appear to belong to a described genus.

Pachyrukhos sp. Several jaw and skull fragments approximate *P. politus* of the Colhué-Huapí in size and may be of that species. The genus is reported at many horizons from the Colhué-Huapí to the Pampean.

This fauna is manifestly of Colhué-Huapí or Santa Cruz age or intermediate between the two. *Colpodon* and *Cochilius* are so far known only from the Colhué-Huapí (and perhaps earlier, in the case of *Cochilius*). *Theosodon* has not hitherto been reported in beds earlier than the Santa Cruz. *Propalaeohoplophorus*, *Hegetotherium*, and *Pachyrukhos* have reported ranges from the Colhué-Huapí into the post-Santa Cruz. The forms listed as allies of *Sciamys* and of *Thoatherium* are not exactly identifiable with known genera, but both suggest pre-Santa Cruz age. The preponderance of evidence thus definitely favors pre-Santa Cruz age. Equivalence with the Colhué-Huapí is entirely possible, but the facies is clearly different and the age may be slightly different, in this case a little later. The occurrence of *Theosodon* does not contradict this conclusion, for many Santa Cruz genera also occur in the Colhué-Huapí, and *Cramauchenia* is not a truly ancestral form.

Section 1, stratum *g*. We found only marine fossils in this thick unit, molluscs, sharks, rays, penguins, whales, etc. Frenguelli (1927, p. 230), however, reported *Theosodon gracilis*, *Hegetotherium mirabile*, and *Zaëdius proximus*. The *Theosodon*, which he figures, is apparently the same as that found by us. Our specimen, at least, does not appear to me to belong to *T. gracilis*. The *Hegetotherium* is perhaps the same as ours, but as Frenguelli only lists this without figure or description this is not certain. Our specimens, as already noted, do not belong to *H. mirabile*, although more fragmentary remains might be mistaken for that species. The *Zaëdius proximus* was identified from scutes, not figured. Being based solely on scutes, the identification is necessarily very uncertain.

It seems very possible, if not probable, that Frenguelli's specimens were from our stratum *e*, and not in actual association with marine fossils, as Frenguelli did not distinguish the three strata here called *e*, *f*, and *g* from each other, including the first two and most or all of the last in his X3. There is, however, the possibility that land mammals do occur in stratum *g*, and that we failed to find them. We did find some very scanty

and isolated edentate remains *on* but not *in* these marine beds. They may have weathered out of them, but the possibilities of transport from higher, or even from lower, terrestrial strata are too great to consider this as conclusive evidence. The marine beds were in large part deposited near the shore, and sporadic land mammals could occur, but there is no conclusive evidence that they do. In any case, the general interpretation of the series is not affected.

I cannot agree with Frenguelli that his mammals prove that the Patagonian exposures near Gaiman are synchronous with the Santa Cruz. The *Zaëdius* or *Zaëdius*-like scutes have no definite bearing on the

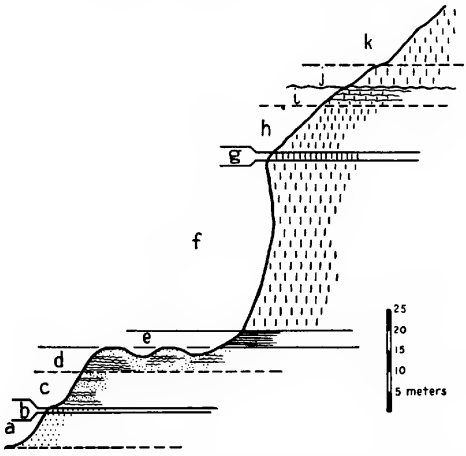

Fig. 3. Section of north wall of Chubut Valley near Gaiman Nuevo.
For description and explanation of reference letters, see Section 2, in the text.

matter, as similar scutes, hardly distinguishable in isolated examples, occur at many pre-Santa Cruz horizons. If, as seems probable, the *Theosodon* and *Hegetotherium* remains are of the same species as those found by us, they could be as old as the Colhué-Huapí. The Colhué-Huapí and Santa Cruz faunas are closely allied, although one is pre- and the other post-Patagonian. They often can hardly be distinguished save on the basis of large collections or fortunate finds of the more distinct genera. If Frenguelli's fossils are from the marine beds, they are probably intermediate in age between Colhué-Huapí and Santa Cruz, and I see no evidence opposed to this possibility.

Section 2, stratum *b*, and similar sandstone lenses in the same formation at somewhat different levels.

Diligent search in these sandstones almost anywhere will reveal a

few bone scraps. Teeth are excessively rare, but do occur. Including the Roth specimens surely from this formation at or near this locality, the following forms are so far known to me:

Turtles—numerous fragments.
Crocodiles—rare small scutes and other fragments.
Snakes—rare vertebral fragments, some of large size and suggesting *Madtsoia* but not as large as the type of *M. bai.*
Mammals—
Polydolops, new species, small and apparently rather primitive.
Monolophodon minutus Roth = *?Polystylops minutus.*
Lelfunia haugi Roth = *Isotemnus haugi.*
Gen. et sp. indet.—A small and primitive notoungulate probably belonging or allied to the family Notopithecidae.

The age can only be Río Chico or Casamayor, as no animals closely similar to these occur at any other levels. Either is possible, but Río Chico age is more probable. The fauna, as far as it goes, suggests this, as the mammals are apparently distinct and primitive species belonging or allied to the more primitive genera of the Casamayor, which is typical of the Río Chico fauna.

Section 2, stratum *h*. This is the level of *Chubutolithes*, a very peculiar concretion or fossil of uncertain origin. The name was given by Ihering (1922) who considered the supposed fossil as probably an invertebrate. Windhausen (1921, p. 26) says that "la interpretación más aceptable es que son coprolitos procedentes de la fauna del Pyrotherium." Schiller (1925, p. 36) records their presence also in the vicinity at Bahía Solano, north of Comodoro Rivadavia as "un *Problematicum, sumamente notable* . . . , que no hemos podido determinar ni mis colegas ni yo. Tampoco lo reconocieron los paleontólogos más famosos del mundo. Casi me inclino a opinar que se trata de un *celenterado*" (italics Schiller's). Frenguelli (1927, pp. 239 and 252) also comments on them, concluding that "a lo sumo podríamos afirmar que ellos representen el molde de la cavidad de algún organismo inferior, que podría ser tanto un celenterado, como un tunicado, etc."

These peculiar objects are nodules generally 30 to 60 mm. in length, ovoid or more elongate, and occasionally quite irregular in shape as if roughly molded of plastic clay and then indented or otherwise deformed. They are composed of volcanic ash of the same character as the matrix in which they occur, cemented with about ten per cent. of calcium carbonate (Frenguelli, 1927, p. 239). The surface is delicately sculptured with indented lines, circling or spiraling around the long axis of the nodule, and between these lines, which are generally 10 to 15 mm. apart,

there are lesser lines, approximately in the direction of the long axis but always strongly curved (all in the same direction) and anastomosing. The effect, as Windhausen said, is much as if a feather had been wound around the nodule. This strange and delicate sculpturing sometimes covers the nodule completely, and in other cases is clearly developed only on one side, the other being smooth or irregular. More aberrant forms are flattened and almost circular, one side rough (or apparently

Fig. 4. The Pan de Azúcar at Gaiman Nuevo. This is the exposure of which a section is given in Fig. 3.

The bench in the foreground is developed on stratum *d* of the section, probably Río Chico Formation, and *e* forms the base of the slope beyond this. The rest of the lower slope, the vertical part of the cliff, and the lower third of the upper slope are the series *f–i*, ?Casamayor. The hard bed *g* forms the cornice, top of the vertical cliff, and *Chubutolithes* occurs just above it. The apex of the hill is formed by the Patagonian Formation, with the here thin and doubtfully separable Trelew beds at its base.

attached to normal matrix) and the other with one main line and the curving network on each side. Not all the nodules show the sculpture, which is intensified or perhaps occasionally developed by weathering (the pattern in any case clearly predetermined by the structure of the nodule). Some contain masses of crystalline calcite, and a few are septarian.

I cannot hazard any definite guess as to the origin of these very strange objects. They are not marine, for they certainly occur in terrestrial strata near Bahía Solano and probably also at Gaiman. They probably are natural molds or casts, since the material is the same as the matrix except for the greater amount of calcium carbonate and they probably are organic in at least a broad sense of the word.

Schiller believed the strata in which they occur at Bahía Solano to be perhaps *Pyrotherium* beds (=Deseado). Frenguelli points out that they cannot be considered guide fossils of this horizon, and believes them probably to be in the Patagonian at Gaiman. As pointed out below, this level is almost surely pre-Patagonian at Gaiman, and possibly Casamayor. It is therefore interesting to note that the beds in which they occur near Bahía Solano are also Casamayor, and not Deseado, as definitely proven by fossils collected there by us and by others. If they are organic and typical of one formation, which is hypothetical but not inconsistent with the known facts, then they characterize the Casamayor.

Section 2, stratum *j*. We did not work long on this horizon and found few mammal remains. The most definitely identifiable is the same species as the unnamed hegetothere of intermediate size from Section 1, stratum e. Both Roth and Windhausen, correctly in my opinion, considered the mammals as in or immediately below the base of the marine Patagonian, and Ameghino identified Roth's material as belonging to his *Colpodon* fauna. Frenguelli considers the horizon as 42.5 meters above the base of the Patagonian, but only one to four meters above the lowest recorded marine fossils. It seems probable that his terrestrial mammals are from slightly below the marine fossils in the same exposures (even if only a few centimeters), although of course not impossible that they are really in the base of the marine beds. The situation is similar to that on the other side of the valley, and it seems reasonably certain that this stratum corresponds with *e* of Section 1.

STRATIGRAPHIC DIVISIONS AND CORRELATION

Considering only the base of the Patagonian Formation and the older rocks, there are in this series three distinct changes in lithology, fossils, or both. The highest of these is between f and g of Section 1, and j and k of Section 2. I believe that these beds correspond, that is, f, Section 1, with j, Section 2, and g, Section 1, with k, Section 2. Frenguelli's very different opinion, which places the beds cited in Section 2 at a much higher level than those of Section 1, was based largely on the probably erroneous identification of the next lower break, discussed below.

The distinction here is that in the lower beds, f, Section 1, and j, Section 2, land mammals occur and marine animals are rare or absent, while in the overlying beds land mammals are rare or absent and marine animals are abundant. On the north side of the valley, as typified by Section 2, there appears to be no unconformity at this point. The change cannot be exactly localized, save for a slight color difference, but in the lower member, from 0 to 6 meters in thickness, mammal bones are

Fig. 5. Small exposure in valley slope southeast of Gaiman, corresponding with the partial section in the text.

The pale tuff in the upper part of the picture and the hard yellow sandstone above the pickhead are Patagonian. The pick is inserted at the erosion plane, more clearly visible to the right of the pick. Below this is the fine, steel-gray sandstone without fossils. Down the zanjón to the left, below the area covered by the photograph, are tuffs with land mammals and no marine fossils.

present and above that they are very rare or absent. We did not actually find land mammals and marine fossils at the same level, the mammals always being below any marine forms in the immediate vicinity, but in some places the difference in level was only a few centimeters, without a clear intervening plane of division. Some other observers speak of the land and sea fossils as mingled. Since the series appears conformable, and since the lower bed in question is variable in thickness and sometimes pinches out entirely, they may only have meant to describe the condition

we found and not to imply actual association of the two types of fossils at one level and place. However, I see no reason to doubt that the latter may occasionally be true, although this would not negative the fact that a division, even if conformable, does exist. The general appearance and other data suggest the theory that still unconsolidated terrestrial sediments were here present when the sea advanced. Being unconsolidated, they did not always form a sharp contact with the later marine

Fig. 6. Detail of concretionary mass in the left-hand side of the exposure shown in Fig. 5.

These appear to be burrows extending from the erosion plane into the underlying softer sands, filled with the coarser sand and triturated shells of the overlying basal marine Patagonian. Larger and simpler burrow-fillings are also common, and the terminal fragment of one is seen in the lower part of the photograph, to the left of the middle.

beds, and in places may even have been churned up or reworked so as to cause some mingling of marine and terrestrial organic remains. I do not believe that the lower bed of Section 2, j, was originally marine, with a few land animals accidently entombed in it.

On the other side of the river in the vicinity of Section 1 (and for several leagues down the valley), the condition is much clearer. Bed f, the equivalent of j in Section 2, is more constant and thicker, 14–15 meters as against 0–6 on the north side. In spite of long search, we did

not find any trace of marine fossils *in situ* in this bed, and it seems highly improbable that they are present. Contrary statements are perhaps due to failure to recognize the presence of a division and to record the precise levels of fossils with respect to it. The top of the terrestrial horizon is almost everywhere sharply delimited when well exposed. The rocks are soft and usually covered with wash, in which case the vicinity of the contact can usually be recognized by a yellower, rusty, and often concretionary zone. When well exposed, there is a sharp and definite bedding plane, with marine fossils above and land mammals below.

Fig. 7. El Castillo, south of Trelew. The whole exposure is in the lower half of the Patagonian Formation. *Ostrea hatcheri*, shark, penguin, and whale remains are common.

Although not together, we found these in places *in situ* within a few centimeters of each other. In a peculiarly favorable exposure two kilometers east of Section 1 (see Fig. 5), the following series occurs (from top to bottom):

Massive tuff with marine fossils—not measured here.

Hard, coarse, yellow sandstone with many shell fragments. From it many burrow fillings lead down into the underlying bed.....0.3 meter.

Soft, steel-gray, fine, cross-bedded sandstone, without fossils except those obviously filling subsequent burrows and really part of the overlying bed. 4.5 m.

White to yellowish tuff, platy toward the top. Land mammals. No marine fossils.....9.5 m.

The presence of a disconformity, or parallel unconformity, below the marine sandstone is here obvious. Below the lowest bed listed is the next unconformity, discussed below.

The inevitable conclusion is that there is here a separate formation which is terrestrial and which contains at least the majority of land mammals collected at this general level in this region. The possible occurrence of occasional isolated land mammals in the overlying marine beds does not affect this conclusion. The time lapse between the deposition of this formation and the incursion of the Patagonian sea was probably slight, as indicated both by the resemblance of this fauna to others clearly post-Patagonian and by local apparent conformity, due, I believe, to the fact that the terrestrial sediments were not consolidated when the marine invasion occurred.

As shown by the fossils, discussed above, the age of this formation is either Colhué-Huapí or slightly later. In view of the wide geographic separation from the typical Colhué-Huapí, the distinction in facies and the possibility of slightly different age, I propose to continue provisional use of the name Trelew (or Trelewense) for this horizon, as proposed by Kraglievich (1930, pp. 157, 160).[1]

On the south side of the valley (see Figs. 8–9) there is everywhere a very obvious unconformity between beds d and e of Section 1. In the formation below this level, no fossils have ever been found, while above it land mammals are fairly common at some localities. The contact is a broadly flat but sometimes locally irregular plane of erosion which is clear and definite wherever it is exposed. Furthermore the lower formation terminates above with a prominent, cornice-forming, platy, irregular, concretionary tuff often brighter in color than the rest of the series and very prominent in the landscape. I believe the special character of this bed to be due to ancient erosion and surface weathering in the time preceding the deposition of the Trelew beds. Frenguelli definitely and also others previous to him, as nearly as one can judge from the scanty published references, believed that this unconformity is found on the north side between the clay-sandstone series and the tuffs, between beds e and f of my Section 2. I am convinced, on the contrary, that it is between my i and j. In the latter position Roth recognized a formation

[1]Kraglievich considered his name a substitution for Ameghino's "Colpodonense," and hence equivalent to the older name Colhuehuapiense of Carlos Ameghino, in the sense in which Frenguelli and I also use that formation name. The type locality of the Trelewense is, however, the region of Trelew, not only because of the derivation of the name but also because Kraglievich explicity gave it because *Colpodon* was found near Trelew. The assumption that Trelewense in this sense and Colhuehuapiense in the Carlos Ameghino-Frenguelli-Simpson usage are the same formation is still unwarranted. That is a correlation which perhaps can be decided, positively or negatively, later. Ameghino's "*Colpodon* fauna" was not from near Trelew but almost entirely from south of Lago Colhué-Huapí.

contact (the top of the "Transition beds" = Deseado in his opinion), but Frenguelli shows no division here (1927, Fig. 37 and p. 239, his beds f and g) and believes the rocks both above and below this level to belong to a single, unified subdivision of the Patagonian.

The contact of e on d in Section 1 and that of j on i in Section 2 are practically identical in appearance and nature. On both sides of the valley, similar, massive, barren tuffs lie below the contact. On both sides

Fig. 8. South side of the Chubut Valley opposite and downstream from Gaiman.

The vertical exposure is the barren ?Casamayor, capped by the cornice-forming, contemporaneously weathered bed. The Trelew beds, poorly exposed, occur on the bench above the cornice. The lighter part of the slope in the distance is the Patagonian Formation and the darker upper part the later sandstones.

the bed immediately below it is a hard, irregular, platy tuff. On both sides the contact itself is a sharp erosion plane; on both it is immediately overlain by a relatively thin tuff with land mammals (apparently of identical age on the two sides), which in turn give way to beds with many marine fossils. If the older correlation is accepted, it is necessary to believe that the massive barren tuffs of the south side become mammal- and reptile-bearing sandstones and clays in the few miles separating the exposures; that the irregular contact tuff disappears in this distance while

another of the same character (the only one in the section) appears at a very different level; that the fossiliferous mammal tuffs on the south side become completely barren and different in aspect on the north while a similar bed with the same sort of mammals appears at a much higher level; that very richly fossiliferous marine beds become completely barren; and that of the two closely similar contacts to be seen on the two sides, that on the south is the most important break in the whole

Fig. 9. Trelew beds overlying the platy top of the ?Casamayor, south of Gaiman.

series, while that on the north is not a break at all. The new correlation here proposed seems to be beyond any reasonable doubt.

The age of the barren tuffs a–d, Section 1, and f–i, Section 2, is doubtful. It is below, and hence older than, the Trelew, and the nature of the contact suggests that the age difference could be considerable. It is above beds probably of Río Chico age, and the contact does not very definitely indicate whether the lapse is long or short. The only suggestion of a fossil is *Chubutolithes*, which casts little or no light on the problem. This barren division must be either Casamayor, Musters, or Deseado.

Any one of these is possible, but Casamayor is somewhat more probable. Lithologically it resembles the more southern Casamayor slightly more than it does any exposure of the other two formations known to me. Its relations to the underlying sands and clays are very like those of the Casamayor to the Río Chico in the vicinity of Puerto Visser and Pico Salamanca. Even the extreme scarcity or absence of fossils is somewhat less surprising for a Casamayor exposure than it would be for one of the Musters or Deseado, and *Chubutolithes* occurs definitely in the Casamayor farther south.

The base of this formation is not exposed on the south side of the valley, but on the north side it is between either d and e or e and f of Section 2. I cannot decide whether e, a bed of clay or bentonite four to four and a half meters in thickness, is part of the lower clay and sandstone series or of the upper bentonitic tuff series. Either the upper or the lower contact could well be an erosion plane. Wherever the exact point of division may be, the lithologic difference between the two series is very marked and all students have agreed that they represent two different formations. It has previously been agreed that the lower formation, the sandstones and clays of a–d, Section 2, are Cretaceous. As they contain Tertiary guide fossils, this is, of course, impossible. Aside from the faunal evidence, given above, their closest resemblance in lithology and also in their relations to the overlying tuff series is with the Río Chico, and it seems probable that they do belong to that formation. As for the older view (Roth, Ameghino, Windhausen) that they represent the Salamanca, this seems impossible, and no good evidence for it has ever been adduced except Ameghino's statement that Salamanca fossils are found in them, which is not true and must have been due to his misunderstanding some statement of Roth's.

STRUCTURE

Very important for many problems of South American geology is the belief, recently and in most detail expressed by Frenguelli but shared by most other geologists, that in this region there is a folded lower series, hitherto considered Cretaceous, followed with angular unconformity by a horizontal or much more feebly folded upper series. In the first place, it is clear that this angular unconformity, if it exists, is not the Cretaceous-Tertiary contact but is in the Tertiary series. In the second place, I could find no evidence in the field that the angular unconformity actually exists at the levels where it has been indicated.

Fig. 10. Part of the thin-bedded series on the south side of the Chubut Valley at La Angostura, above Gaiman.

The most important evidence adduced for this angular unconformity is briefly this:

1. Several isolated exposures of the Río Chico ("Dinosaur beds" or Upper Cretaceous of previous authors) west of Gaiman are tilted or contorted, while the later beds, in the adjacent cliff, are horizontal or only more gently inclined.

2. On the south side of the valley at "La Angostura," between Gaiman and Dolavon and beginning about one league west of my Section 1, there is a long cliff formed by usually markedly stratified and thin-bedded sands, clays, and tuffs, in the lower part with much chalcedony and gypsum (see Fig. 10). This series shows some irregular gentle folding and small faults, while some blocks of it may be more strongly tilted. It is at about the same altitude as the barren tuffs a–d of Section 1, into which, however, it cannot be traced laterally due to the lack of good intermediate exposures. Frenguelli believes this series to represent the "argiles fissilaires" which, according to widely accepted views, are supposed to be of Cretaceous age where typically developed farther south in Patagonia, to be folded, and to underlie the Tertiary (usually the Casamayor) with angular unconformity. He explains the lateral substitution of this fissile series for the more massive beds near Section 1 by supposing that the former are the upper and the latter the lower parts of one formation which is tilted westward, or with a strong western component, and then planed off at its upper contact so that near Section 1 the lower part underlies the Patagonian and at La Angostura the upper part.

As to (1), the conclusion drawn does not seem to follow from the observed facts. In isolated blocks, where the overlying beds have been eroded off and continuity cannot be established, the Río Chico is sometimes tilted in a way different from that of the upper beds in nearby, but distinct, exposures (Fig. 11). But wherever both occur in one exposure or where the Río Chico is actually visible at the base of the main cliff (as at the Pan de Azúcar), upper and lower series are perfectly parallel so far as the eye can see or instrument surely measure (Fig. 4). The possible conclusions are, then: (a) that an angular conformity exists in some places and not in others in the immediate vicinity and that the upper beds happen to have been eroded away wherever it does exist, (b) that both series or parts of both are folded, more or less parallel to each other and the strongest folding is farther out in the present valley where the upper beds are eroded away, or (c) that there is no real strong folding and that some of the smaller blocks of the lower formations, left outlying by

the retreat of the main cliff, have slumped on the underlying greasy clays. I see no absolutely decisive evidence in favor of any one of these three possibilities, but (a), the only one in accord with previous interpretation, seems to me far the least probable.

As regards (2), it must first be mentioned that the correlation of these beds of La Angostura with the "argiles fissilaires" is highly dubious. I cannot agree that there is any real lithologic resemblance between these

Fig. 11. The north valley wall, near Gaiman Nuevo and a short distance west of Fig. 4.

The cliff is formed by the ?Casamayor, with Trelew and Patagonian at the top. The foreground is Río Chico, normally nearly horizontal and parallel with the beds of the main cliff, but in some isolated blocks (as in the distance, to the left) tilted.

beds and the "argiles fissilaires" of the Colhué-Huapí, Mazaredo, or Río Deseado regions. The one typical rock of the "argiles fissilaires" is an opalized tuff, which is not present at all at La Angostura so far as I saw. No truly fissile clays or, still less sands like those typical of the Angostura series occur in any of the many true "argiles fissilaires" exposures that I have seen. If, as is possible, these beds are of the same age as the "argiles fissilaires," this is in spite of and not evidenced by, their lithologic character. If they are the upper part of series a–d, Section 1,

then they cannot be of "argiles fissilaires" age, as that would put them above tuffs which cannot be older than Casamayor, and the typical "argiles fissilaires" are always below the Casamayor tuffs. The correlation, however, is not very important from the present point of view. It would go too far afield to discuss the matter further here, but it now seems beyond reasonable doubt that the typical "argiles fissilaires" are not Cretaceous but Tertiary and are essentially parallel to the Casamayor wherever both are now known to occur. It is probable that they are

Fig. 12. Part of the fissile series of La Angostura, showing distorted block.

In this case it is obvious that the block is merely a slumped segment of the main cliff and that its distortion is purely superficial and not tectonic. It is believed that this is the true interpretation of other apparently folded exposures where the relationship to unfolded strata cannot be clearly seen and that this condition explains much, perhaps all, of the supposed strong folding in this region and in some other parts of Patagonia.

merely a lithologic facies of Casamayor beds, although this is not yet rigidly proven.

The evidence for folding and angular unconformity from these Angostura strata thus receives no support from analogy with conditions farther south and depends on local observation and especially on the apparent lateral substitution of these for beds of quite different character near Section 1. The two cannot be traced into each other, but in the

poor and small exposures between them the thin-bedded Angostura rocks disappear, and apparently at the same level and within two or three kilometers appear massive barren tuffs. If explainable because of the attitude of the lower beds, this would demand a higher dip than any actually observable. In rather detailed study of this side of the valley we found the dips which can be considered as reasonably persistent to be very low, and not to the west. Except for obviously local disturbances, the dip opposite Trelew and Gaiman was not observed to exceed one half degree, and was generally south or even southeast, not regionally west. Local and not very marked contortions in the Angostura exposures are frequent, as might be expected from their lithologic nature, and there are also many large blocks that have slumped from the cliff (Fig. 12), are hence sometimes more steeply inclined, and might be mistaken for bedrock exposures, but the real regional dip of this formation, also, seemed to us to be extremely small, and not definitely to the west. The relation of the Angostura beds to the more usual sections is not at all clear, but it seems hardly possible that it involves marked folding. As a hypothesis, still very tentative, the thin-bedded series may be a lateral lacustrine facies.

As far as we saw, or the literature indicates, there is no single exposure here on the south side, either, where an angular unconformity can actually be seen. In a series with several distinct erosional breaks, it is to be expected that small angular unconformities exist, but the evidence is still lacking. If they are present, it seems almost certain that the angle involved is less than a degree, which can hardly be considered as typifying a strong early type of folding as contrasted with a gentler, later Tertiary type, in accordance with the views of Windhausen (e.g., 1924), for instance, which have been considered as applicable to this area. Aside from the usual very gentle and local folding and faulting affecting all beds almost equally, as far as can be positively determined, there seems to be a regional dip across the valley around Gaiman approximately to the south, possibly southeast.[1]

Assuming that the local correlations between Section 1 and Section 2 here proposed are correct (and I hardly see how any other interpretation can be made on the basis of the new data here mentioned), then the dubious nature of the supposed widespread angular unconformity is also suggested by its being placed at very different levels in different sections, although considered as the same throughout. Near Section 1, it was

[1]This is a statement of as much as seems really supported by good evidence in the Gaiman region, and not a generalization. There is strong folding of Tertiary beds as late as Deseado in some localities. As far as I know the Patagonian and later formations, however, are never markedly folded or tilted in the meseta region.

supposed to be between the barren beds doubtfully Casamayor and the Trelew, and in Section 2 at the much lower level between the Río Chico and the ?Casamayor.

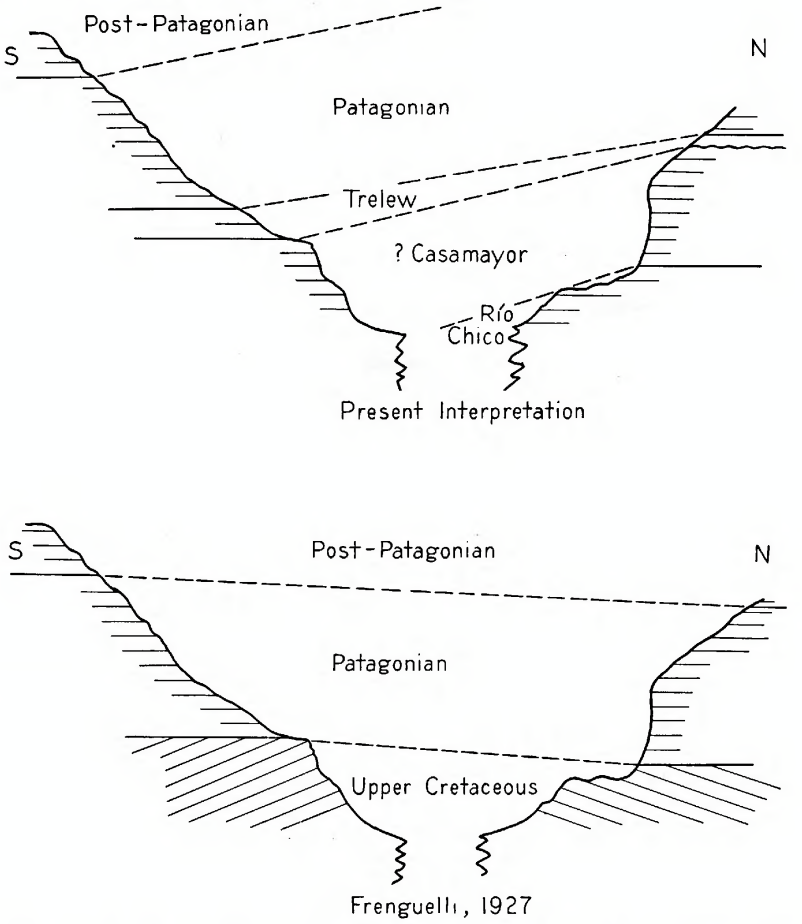

Fig. 13. Diagrammatic sections across the Chubut Valley in the Gaiman region, approximately south to north. The broad valley bottom, without bedrock exposures, is omitted.

Above, interpretation expressed in the present paper. Below, that of Frenguelli, 1927. Frenguelli does not give the section in this form, but the diagram is combined and simplified from his several published sections and is believed to represent his views of 1927 accurately. The correlation lines in the upper diagram do not represent dip, but are steeper (although in the same direction), due to the omission of several miles between the two sections.

The accompanying diagram (Fig. 13) shows the conclusions as to stratigraphic subdivision, correlation, and regional structure here reached, in contrast with the views of Frenguelli—the latter being given because they are recent, most fully documented, and based on such capable field work, and not to single them out for individual criticism.

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ADDENDUM

Since this paper went to press, I have received a paper by Dr. Alfredo Castellanos (Quid Novi? Revista de las Asociaciones de Exalumnas y Padres de la Escuela Normal Número 2, Rosario, Argentina, Año II, Núm. 6, 1934), in which he uses the name "Ríochicoense" in a sense different from that which I have given to "Río Chico" or "Ríochiquense" in this paper and elsewhere (also recently used in papers by others). As Castellanos cites no previous authority (and I can find none), I presume that a new name is intended, although no definition is given beyond a parenthetical equation with one of Ameghino's names, itself of very dubious value. Castellanos' name is a virtual homonym of mine, which was published before his and with a full definition.